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Sequence Stratigraphic Setting of the Late Miocene Sediments in EBB Field, Southeastern Niger Delta

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Abstract

This work incorporates biostratigraphic record from analyzed ditch cutting samples, gamma ray and resistivity logs and a seismic volume in developing a sequence stratigraphic framework for the Biafra Member sediments in EBB field, shallow offshore, Niger Delta. Key stratigraphic surfaces and contacts were identified and delineated. Sediments within EBB field have been found to be of Late Miocene geologic age. The field is marked at the top by a 5.6Ma sequence boundary and a lower limit not penetrated by the wells. A combination of biofacies evidence and stratal stacking pattern was used in the delineation of systems tracts. Top coarsening-upward highstand systems tract sands are underlain by fining-upward shales of the transgressive systems tract and basal prograding sand-rich sediments of the lowstand systems tract defines a complete systems tract of a sequence deposited in the studied region. The sand-rich lowstand systems tract is the main reservoir unit of the field with a network of NW-SE and NE-SW trending bounding faults providing a good trapping configuration. The transgressive systems tract overlying the lowstand systems tract is a regional seal while suspected deep-seated Akata shales as well as shale interbeddings within the reservoir sands are the source rocks.

Keywords: Sequence, Systems tracts, Progradation, EBB field, Niger Delta.

Introduction

The Niger Delta, west central Africa aroused global interest when it became one of the world's leading hydrocarbon provinces. The science and trade of hydrocarbon exploration has generally recorded impressive successes across the mature and frontier parts of the basin. However, failed prospects arising from the apparent difficulty in identifying key elements of the petroleum system-source, reservoir and seal from the integral components of a depositional sequence - LST, TST and HST are prevalent.

According to Carol and Ejedawe (2012), examination of Niger Delta data shows that well failure is

attributed to fault seal failure, lack of valid trap, poor reservoir development and migration by-pass. The high risk factor coupled with marked instabilities in the global oil market remains top issues eliciting mitigation. The prevailing lulls notwithstanding, the search for hydrocarbon especially with more assuring techniques is apt to the geoscientists since global appetite for fossil fuel-driven energy is constantly on the increase. Neal et al. (1993) documents that no exploration technique flawlessly locates a potential reservoir, but sequence stratigraphy come close and that an understanding of global changes in sea level aids the interpretation of the local arrangement of sand, shale and carbonate layers. This enhanced understanding of depositional mechanics steers explorationists toward prospects missed by conventional interpretation.

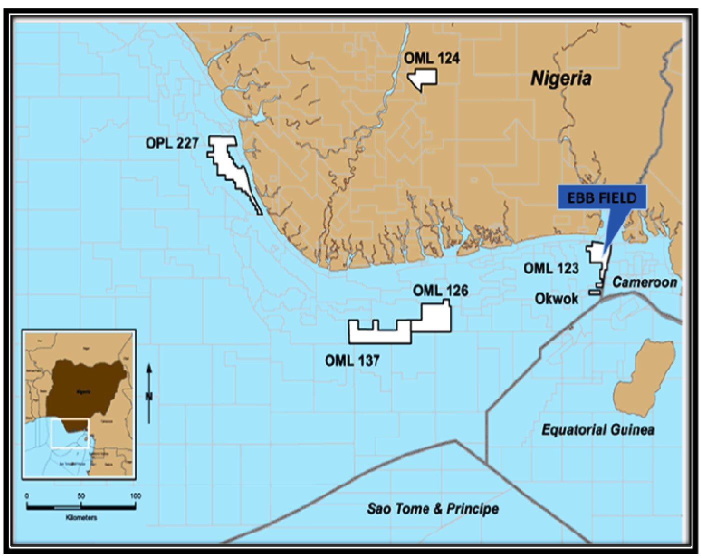

Fig.1. Study location (Source: www.addaxpetroleum.com)

Tuttle et al. (1999) developed a sequence stratigraphic model for the central portion of the Niger Delta, Pacht and Hall (1993), Stacher (1994), Stacher (1995), Reijers et al. (1997), Oweyemi and Willis (2006) and Magbagbeoloa and Willis (2007) among other workers have highlighted various and far-reaching sequence stratigraphic applications in the Niger Delta.

Geology of the Region

The Tertiary Niger Delta with a sediment thickness of approximately 10 kilometers in its depocenter (Kaplan et al. 1994) has three main sedimentary Formations; a basal Akata Formation dominated by marine shales, turbidite sands and subordinate silt and clay; a middle hydrocarbon-bearing Agbada Formation composed of paralic siliciclastics and a topmost Benin Formation constituted of alluvial and upper plain sands.

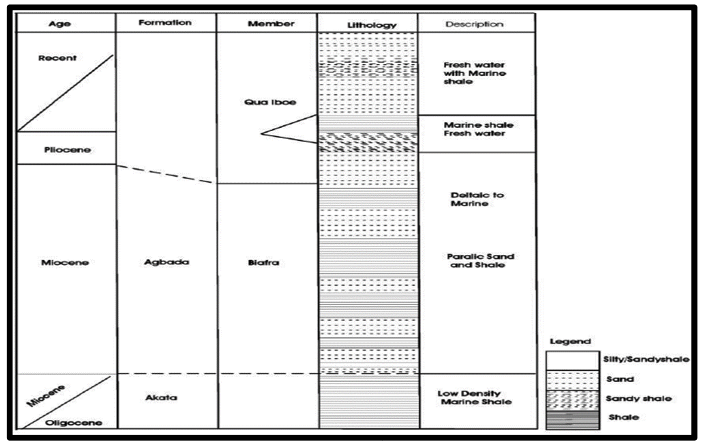

Fig. 2. Generalized stratigraphy of Eastern Niger Delta (Modified after Evamy, 1978).

EBB field is located in the southern part of OML 123, shallow offshore Niger Delta (Fig.1). The stratigraphy of this part of the Delta is greatly modified by a Miocene volcanicity-triggered shale diapirism and sea level fall. Consequently, the paralic Agbada Formation in this area has three subdivisions namely: Biafra, Rubble and Qua Iboe Members (Fig.2). Further complex modification is ascribed to a disconformity surface known as the Qua Iboe Unconformity that developed following the catastrophic failure and basinward slide of a large portion of the southern margin of the Niger Delta prism around 6.3 million years ago (Bruso et al. 2004).

The complex geologic configuration of this part of the Delta where EBB field is located accounts for the

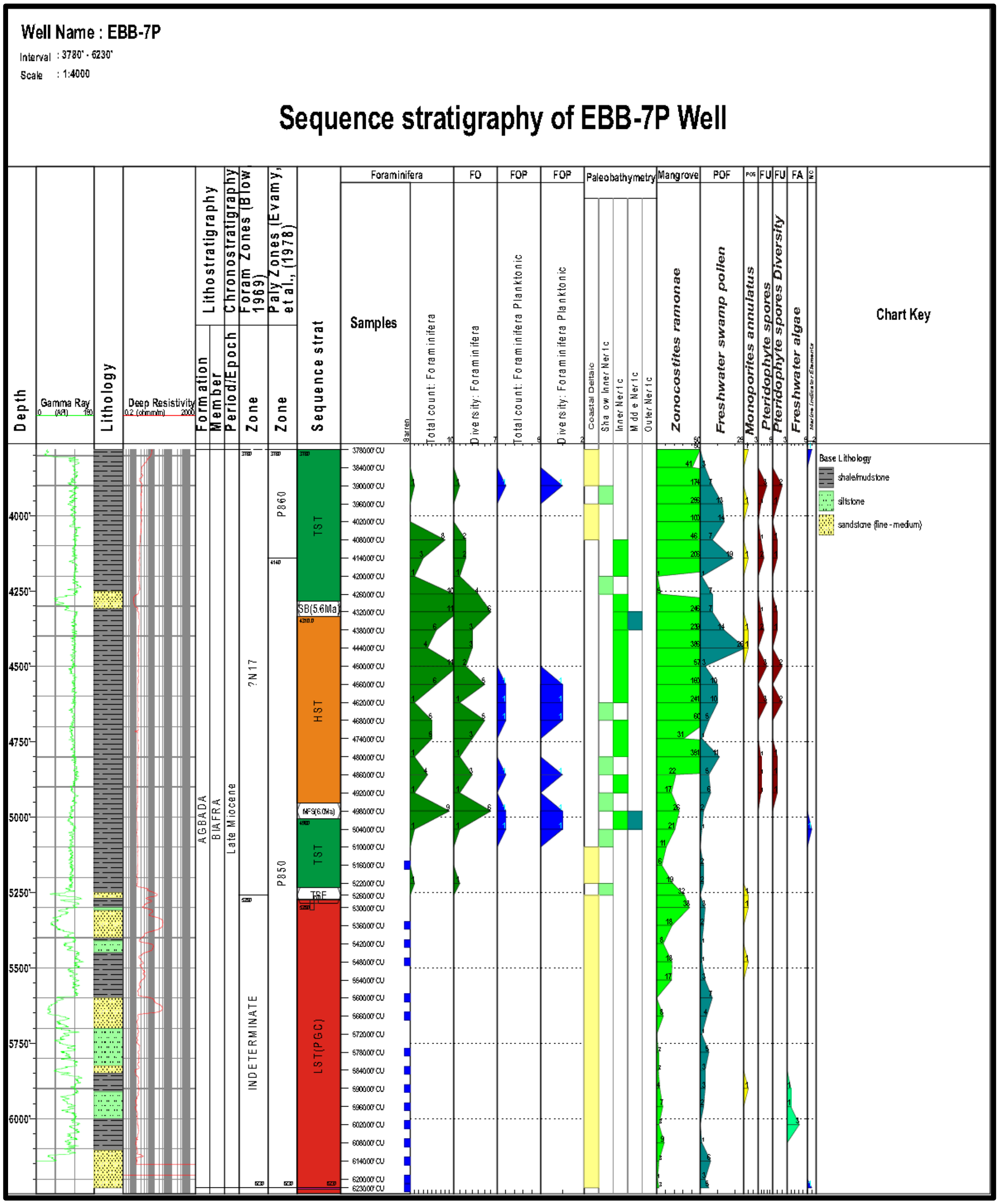

Fig. 3. Events chart and sequence stratigraphic summary of well EB-7P.

poor understanding of its petroleum systems; hazy knowledge of true reservoir extents and faulty field management strategies.

This work therefore seeks to develop a sequence stratigraphic framework for EBB field and adjoining fields with similar characteristics that will guide in field management plans.

Material and Methods

The following data set comprising wireline logs (gamma ray and resistivity) for 11 wells, checkshots, seismic volumes and ditch cutting samples were used and integrated in this study.

The ditch cutting samples were analyzed for their foraminiferal, palynomorph contents and paleobathymetry from where the ages and key surfaces were determined. The logs in LAS format and deviation surveys were then loaded into Schlumberger Petrel software after adequate quality control (QC) checks. The logs were correlated across the field and sequence stratigraphic surfaces deduced from biostratigraphic analysis were integrated. Seismic sequence analysis was carried out as crosschecks aided a successful well-seismic-tie. Strata stacking pattern were examined to enable mapping and integrated with biostratigraphic evidence in the delineation of systems tract on logs and seismic section.

Results and Discussion

Biostratigraphic Analysis: Results from ditch cutting samples collected and analyzed from well EB-7P shows that sediments within the field were deposited within one foraminiferal zone, N17 and Palynofloral P800 zone of late Miocene age. This conclusion was based on the presence of *Uvigerina peregrina, Quinqueloculina vugaris, Quinqueloculina seminulum* and *Amphistegina lessoni* (Petters, 1982) and the single occurrence of *Sphaeroidinellopsis seminulina* (Blow, 1979) at 3900ft as well as the occurrence of *Nympheapollis clarus* at 4140ft of the well. Key sequence stratigraphic surfaces (MFS and SB) were picked and correlated to the third order cycles of Haq et al. (1988). The Maximum Flooding Surface (MFS) was picked on the basis of faunal maxima, associated with very high gamma ray log and a low resistivity log reading which coincides with 4980ft of the analyzed well (Fig.3). The Sequence Boundary (SB) on the other hand was picked on the basis of faunal minima, associated with low GR log and high resistivity log readings coinciding with 4310ft of the analyzed well. The MFS and SB are dated 6.0Ma and 5.6Ma respectively by correlation with the third order cycles of Haq et al. (1988). The mapped events for EBB field were successfully traced on a STRATABUGS-generated chart (Fig.3).

All three systems tracts: Lowstand, Transgressive and Highstand systems tracts (LST, TST and HST) were identified across the field. Their identification and delineation was based on log stacking patterns and microfossil distribution. The Niger Delta sequence stratigraphic indicator polymorphs are given in (Fig.4).

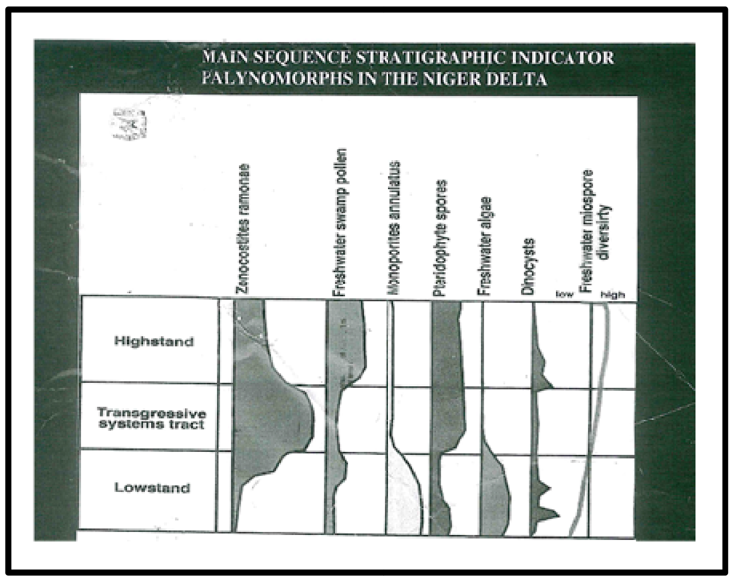

Fig. 4. Niger Delta sequence stratigraphic indicator polymorphs.

The Highstand systems tract (HST) share similar log motifs with the LST (coarsening upwards) but differ in floral characteristics. This systems tract was delineated on the basis of characteristic highest occurrence of Freshwater swamp pollen, higher *Zonocostites ramonae* and Pteridophyte spores, low Dinoflagellate cysts and *Monoporites annulatus* as well as lowest Freshwater algae.

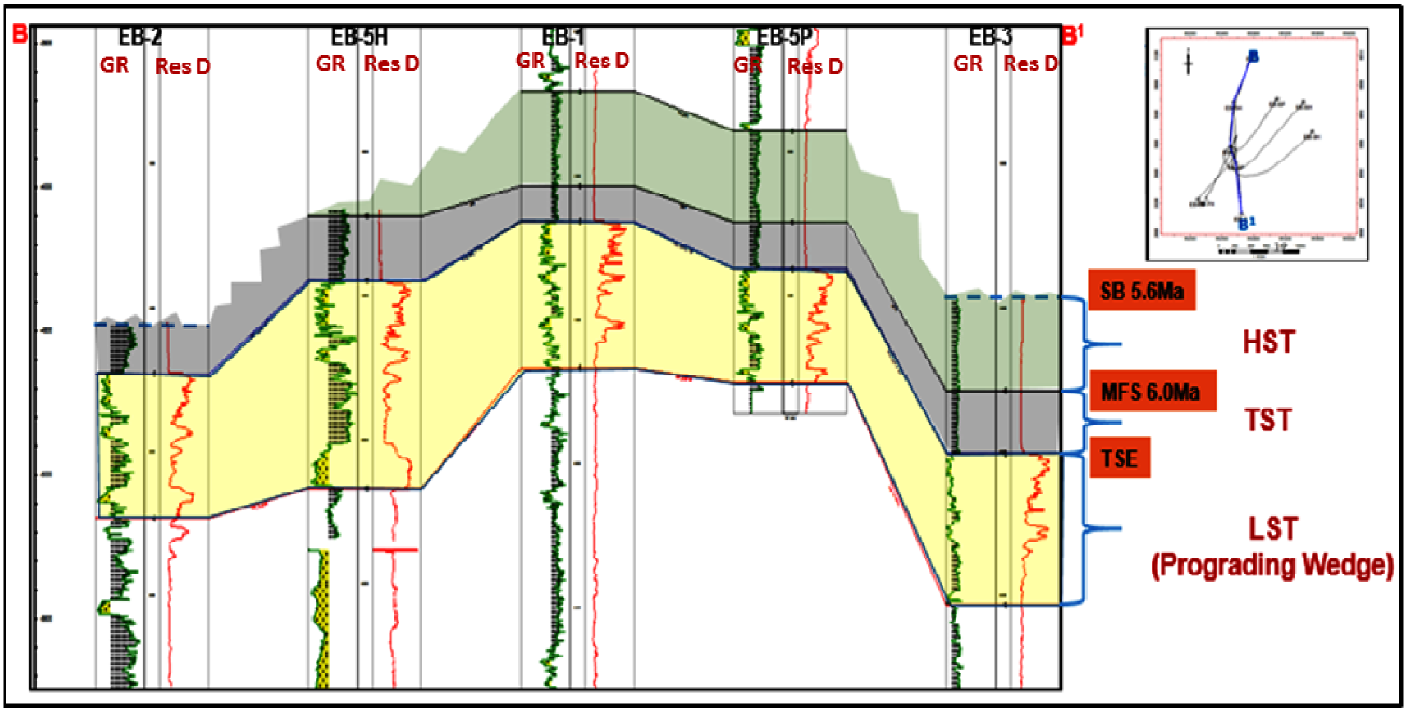

Fig.5. N-S (B-B[1]) oriented sequence stratigraphic correlation of EBB field.

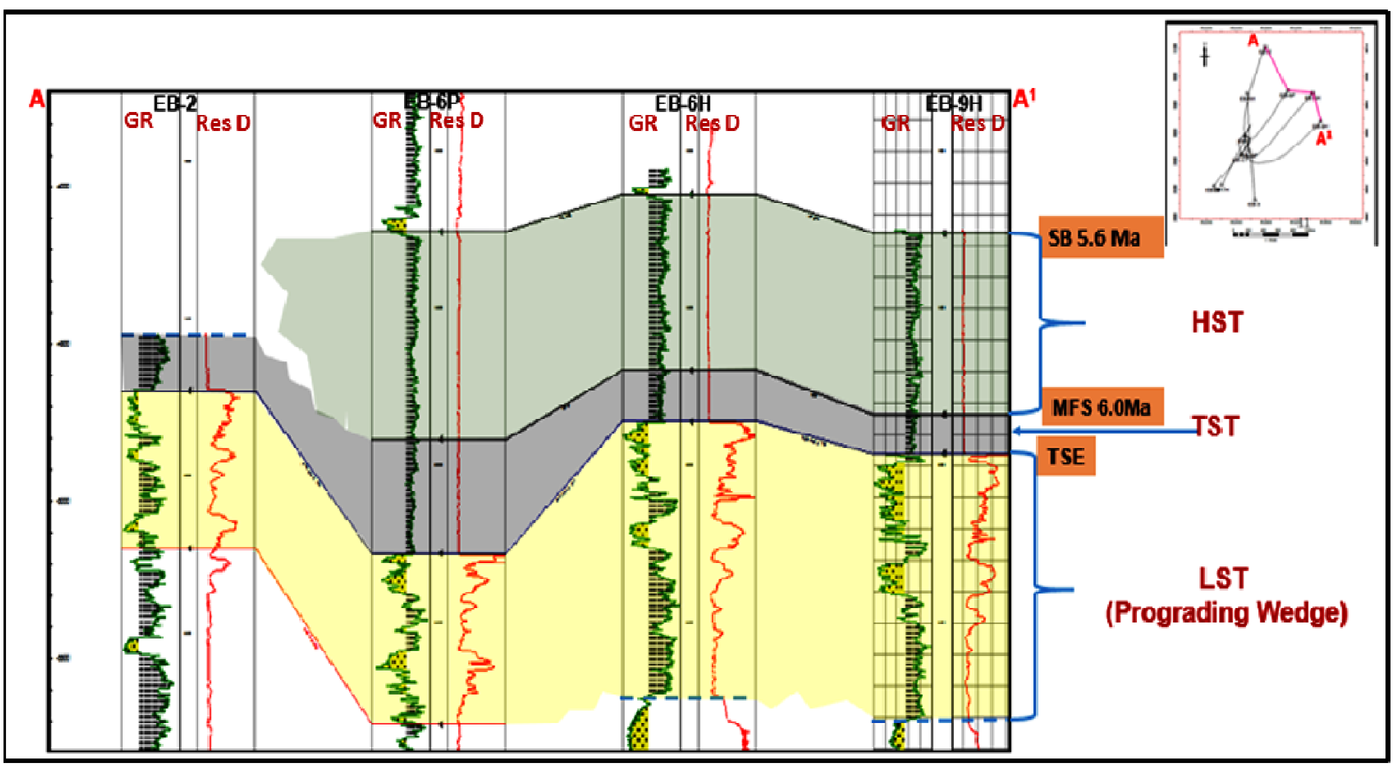

Fig.6. NW-SE (A-A[1]) oriented sequence stratigraphic correlation of EBB field.

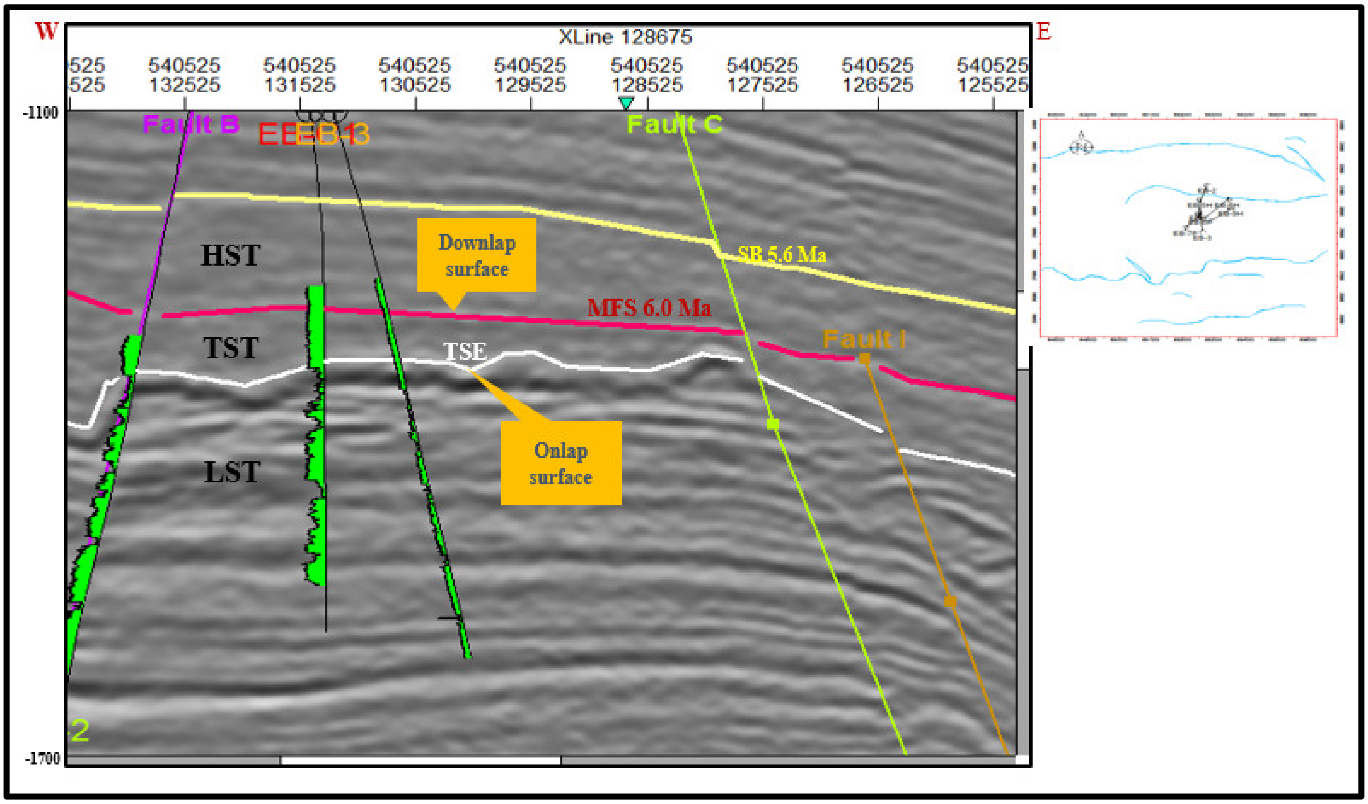

Fig. 7. Seismic sequence stratigraphic framework of EBB field.

The Transgressive systems tracts (TST) has associated retrograding (fining upwards) log motifs and highest occurrence of *Zonocostites ramonae* and Pteridophyte spores, low Dinoflagellate cysts and *Monoporites annulatus* as well as lowest Freshwater swamp pollen and Freshwater algae.

The Lowstand systems tracts display prograding (coarsening upwards) log motifs. Further delineation was on the basis of the gradual transition from an initial highest to a later lower *Zonocostites ramonae*, higher *Monoporites annulatus,* high Freshwater algae, low Freshwater swamp pollen, low Pteridophyte spores and Dinoflagellate cysts.

Sequence Stratigraphic Correlation

Delineated surfaces and systems tracts on well EB-7P were correlated across all the wells along different cross sections to observe beds and sequence behaviors in different orientations (Figs. 5 and 6). The sequence stratigraphic layouts as measured in all the wells across the field are summarized in Tables 1- 3.

Table 1. Thickness of LST as measured across EBB field.

Well	EB-3	EB-7P	EB-C1	EB-5P	EB-1	EB-6P	EB-2
Thickness(ft)	527.78	627	565.83	391	527.78	522	574

Table 2. Thickness of TST as measured across EBB field.

Well	EB-2	EB-5H	EB-6P	EB-6H	EB-1	EB-9H	EB-5P	EB-C1	EB-7P	EB-7H	EB-3
Thickness(ft)		256.07	380	199.74	187.44	169.01	182.33	176.39	273.75	270.05	244.81

Table 3. Thickness of HST as measured across EBB field.

Well	EB-7P	EB-5P	EB-9H	EB-1	EB-6H	EB-6P
Thickness(ft)	670	321	571	293	569	522

Seismic Sequence Stratigraphic Analysis

This analysis is based on the seismic sequence stratigraphic concept documented and proposed by Mitchum (1977), that seismic reflectors on acoustic geophysical cross sections are closely related to chronostratigraphic surfaces or time boundaries. The condensed section with typical transparent low amplitude has the maximum flooding surface at its center and is bordered at the top by a high amplitude sequence boundary as well as high amplitude transgressive surface below. All surfaces correlated on logs were integrated on seismic section (Fig.7)

Sediments of EBB field were therefore deposited within one sequence defined at the top by a third order sequence boundary (SB 5.6 Ma), a maximum flooding surface (MFS 6.0 Ma). The ages were determined by correlation of the surfaces to the third order cycles of Haq et al. (1988). Biostratigraphic evidence showed that the lower limit of the sequence was not penetrated by the wells in the field.

The HST bounded by a sequence boundary and maximum flooding surface is associated with prograding lithofacies while the TST which is the regional seal is composed of retrograding shale facies. The TSE terminates at a transgressive surface of erosion (TSE) separating the upper transgressive units from the lower prograding units defined as the LST. All reservoirs of the field are located within the lowstand systems tract while the shale interbeddings within the hydrocarbon-bearing sands as well as the deep-seated shales beyond the total depth of the studied wells are the source rocks. Northwest-Southeast and Northeast-Southwest trending growth faults and subordinate antithetic faults developed a good trapping configuration and are key buildups to a valid petroleum system.

Conclusion

A sequence stratigraphic setting for EBB field comprising of one sequence bounded by a third-order sequence boundary, picked on the basis of faunal minima, associated with low gamma ray and high resistivity log values have been developed. Prograding sediments of the HST underlain by sealing transgressive shales (TST) with further underlying sand-rich, hydrocarbon bearing LST and a combination of growth faults defines the petroleum system around the southeastern shallow waters of the Niger Delta. This study has displayed the invaluable influence of biostratigraphy over the validity of developing a sequence stratigraphic framework. The presentation of the spatial distribution of the elements of the petroleum system (reservoir, source and seal) as delineated and documented in this work will be most valuable in future development plans especially with regards to the parts of the field where reservoirs are thickest or most developed. It is also envisaged that adjacent fields with similar characteristics will find the results documented in this work very helpful.

Acknowledgement

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